A Comparative Study of Capacitated Vehicle Routing Problem Heuristic Model

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Abstract CVRP is a variant of VRP that can be used to find the minimum distance and number of vehicles. In this paper, three algorithm for initial solutions are compared to find the minimum distance for shipping goods from distribution center to all outlets routinely in West Jakarta – Improved Clarke and Wright (ICW) algorithm, Karagul Tokat Aydemir (KTA) algorithm , and Sweeping – Cluster First Route Second algorithm. The results show that Sweeping algorithm is the shortest total distance compared to other two algorithm which is 48.57% shorter than KTA algorithm and 33.33% shorter to ICW algorithm. Larger sample sizes need to be evaluated to strengthen this findings.

***Index Terms*—CVRP, ICW, KTA, Sweeping algorithm**

I. INTRODUCTION

Vehicle Routing Problem (VRP) and its variant have very important contribution in the area of distribution management or freight transporation. Many companies are facing problems that relates to transportation of people, goods or information. Transportation costs is about one third or two third of total logistics costs and that is why efficiency improvement is a major concern [1] and whatever the type of distribution is, one must produce the minimum cost [2], in other words to achieve cost efficiency and cost effectiveness in a fierce competition [3]. One of VRP variant is Capacitated Vehicle Routing Problem – CVRP.

CVRP is the most common variant of the Vehicle Routing Problem VRP [4] and is a basic modification of the initial VRP problem [5]. There are two variants of CVRP, one is a homogeneous variant – called Uniform Fleet CVRP and the other is heterogeneous variant – also called Mixed Fleet CVRP. In homogeneous variant, each vehicle has the same capacity and in heterogeneous variant, each vehicle has its own capacity [6]. CVRP is categorized as NP (Nondeterministic Polynomial) – hard problem. The basic concept of CVRP is to find routes that minimizes traveling distance and total number of vehicles used [7]. A route is a sequence of locations or visited customer that a vehicle must visit along with the indication of the service it provides. The vehicle must start and finish its tour at the depot [8], [9]. CVRP has an additional constraints such as capacity constraint for a vehicle and variable demand at different nodes. Service providers must deliver services to customers at right location to a right person with a right quantity of supplies at the right time to win the customer's satisfaction [10]. The route must satisfy the constraints that each customer must be visited once, and the demands of the customers are totally satisfied and the vehicle capacity is not exceeded for each route.

In this case study, a comparative study for three heuristic methods of CVRP will be made: Improved Clarke and Wright – ICW algorithm, Karagul Tokat Aydemir - KTA algorithm, and Sweeping algorithm – Cluster First Route Second algorithm. These three methods are good for initial solutions in VRP. ICW is an improved method from Clarke and Wright – CW algorithm that is most widely applied for solving CVRP and the applications of CW have continued since it was proposed since 1964 [11]

KTA algorithm is a physics-based optimization algorithm for obtaining initial solutions of VRP and the average deviations of initial solutions from best known solutions are about 30% [12], [13].

Sweeping algorithm – Cluster First Route Second algorithm has an advantage point which can produces good solution within the reasonable time limit [14]. Sweeping algorithm is a good example of the cluster first route second approach [15].

These three algorithms for CVRP will be compared and applied in this case study that happen routinely and continously at this company. Study will focus on delivery from distribution center to all outlets in West Jakarta.

II. METHODS

There are three heuristic algortihms of CVRP that will be compared in this study:

A. An Improved Clarkee and Wright Savings Algorithm – ICW Algorithm

This method was proposed by T.Pichpibul and R.Kawtummachai. This algorithm was tested with 84 problem instances in which 68 instances were found optimal solutions and the average of deviation between their solution and the optimal was very low, only about 0.14%.

ICW is an iterative improvement approach designed to find the global optimum solutions. The new savings list replaces the previous savings list only if the current solution is better than the previous one. The tournamen size, T is a random number between two and six. Set of saving values is chosen from the saving list and is picked out by roulette wheel selection process. The relationship among savings number, n, savings value, s_n, selection probability, p_n, and cumulative probability, q_n is:

$$p_n = \frac{s_n}{\sum_{i \in T} s_i} \text{ for } n \in T$$

$$q_n = \sum_{i \in n} p_i \text{ for } n \in T$$

This process is called Two Phase Selection Procedure.
The flowchart is shown below in figure 1:

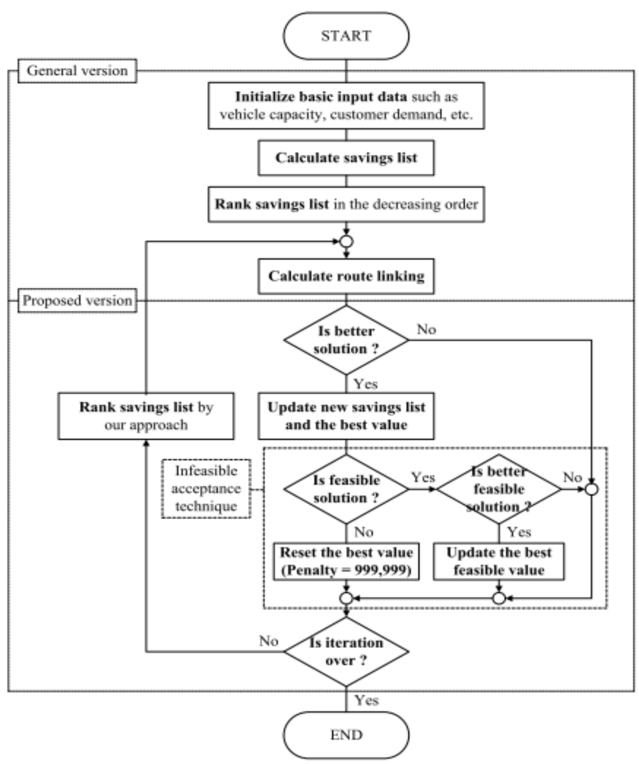

Fig 1. Improved Clarkee and Wright

The method of selection starts by spinning the roulette wheel with a random number, r with range between zero and cone. If $r \le q_1$ choose the first savings value s_1; and if $r \ge q_1$ choose the n^{th} savings value, s_n $(2 \le n \le T)$, for example $q_{n-1} < r \le q_n$. The selected savings value is listed in new savings list. And the selected value is deleted from next tournament selection operation in order to avoid repetitive value. This process is repeated untuk the last savings value is picked out from the savings list.

The savings s_{ij} for a pair of customers v_i and v_j is calculated as follows:

$$s_{ij} = c_{oi} + c_{oj} - c_{ij}$$

This savings is defined as the savings in distance that happen when two customers served each other by the same vehicle in this paper.

B. Karagul Tokat Aydemir - KTA Algorithm

This algorithm is originated from the name of founders: Karagul, Tokat dan Aydemir. The basis of this is Newton's law of mass gravity. This algorithm is categorized as an artificial physical optimization algorithm. The approach is based on these following equations:

$$X_i^c = \frac{q_i . d_i}{\sum q_j} \qquad \text{where i = 2, 3, 4, ...n}$$

X_i = mass gravity of warehouse where i is customer coordinate

q_i = quantity demanded by customer (i = 1 store definition)

d = distance of customer's warehouse (1st row of distance matrix and n-1 customer number)

The above equation states between warehouse and customer's places are examined and force calculations are made.

$$X_{ij} = \frac{q_i . d_i + q_j . d_j}{(q_i + q_j) d_{ij}} \qquad \text{where i = 2, 3, 4, ...n-1; j = i+1,...,n}$$

The above equation shows the relationship between the locations where the customers located and the strengths of masses between the warehouse and customer sites are considered and developed [16].

TABLE I
CREATION OF WEIGHT MATRIX

Demand (qi)		q_1	q_2	q_3	q_4	q_5	q_6
Customer	**Store**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
1 Store	-	X_2^c	X_3^c	X_4^c	X_5^c	X_6^c	X_7^c
2 C1		-	X_{23}	X_{24}	X_{25}	X_{26}	X_{27}
3 C2			-	X_{34}	X_{35}	X_{36}	X_{37}
4 C3				-	X_{45}	X_{46}	X_{47}
5 C4					-	X_{56}	X_{57}
6 C5						-	X_{67}
7 C6							-

TABLE II
MASS GRAVITY FORCE MATRIX SOLUTION DISPLAY

Demand (qi)		1	2	3	4	5	6
Customer	**Store**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
1 Store	-	X_2^c	X_3^c	X_4^c	X_5^c	X_6^c	X_7^c
2 C1	X_2^c	X_2^c	X_{23}	X_{24}	X_{25}	X_{26}	X_{27}
3 C2	X_3^c	X_{23}	X_3^c	X_{34}	X_{35}	X_{36}	X_{37}
4 C3	X_4^c	X_{24}	X_{34}	X_4^c	X_{45}	X_{46}	X_{47}
5 C4	X_5^c	X_{25}	X_{35}	X_{45}	X_5^c	X_{56}	X_{57}
6 C5	X_6^c	X_{26}	X_{36}	X_{46}	X_{56}	X_6^c	X_{67}
7 C6	X_7^c	X_{27}	X_{37}	X_{47}	X_{57}	X_{67}	X_7^c

There are two phases to do this algorithm [17], [18]:

1. Preparation phase:
   a. Calculate depot –vertex mass forces
   b. Calculate Mass Gravitational Constants
   c. Calculate Vertex – Vertex Mass
   d. Create Mass Force Matrix
   e. Assign Depot – Vertex Mass Force values to diagonal cells in Mass Force Matrix

2. Implementation phase:
   a. Choose minimum value in first row and close the chosen row r_1 and column c_1
   b. Go to row c_1, find maximum value which gives the nearest customer c_2. Then add vertex c_2 to the route
   c. Close row c_1 and column c_2
   d. Repeat step 2b until all rows are closed. Then get one TSP solution
   e. Other n TSP solutions are obtained from mass force matrix from each row by ordering the vertices in decreasing order at each row
   f. Considering the capacity constraints (Q) and all (n+1) TSP solutions are converted into CVRP routes
   g. From (n+1) CVRP routes, choose route structure with minimum total cost.

C. Sweeping Algorithm – Cluster First Route Second Heuristic

This algorithm is a method for clustering customers into groups so that customers in the same group are geographically close together and can be served by the same vehicle and this algorithm consists of two phases, the first one is clustering phase and the second one is routing [19]. Assume that customers are points in a plane with Euclidean distance as cost. The distance between (X_i, Y_i) and (X_j, Y_j) is calculated. The steps to do this algorithm are following [20]:

1. Phase one:
   a. Compute the polar coordinates of each customer with respect to the depot. Then sort the customer by increasing polar angle
   b. Add loads to the first vehicle from the top of the list but not exceeds the capacity of vehicle. If loads exceed the capacity, then continue with the next vehicle. This step continues until all customers are included.
   c. The value of angle, θ is given by $\theta = \tan^{-1}(Y_i / X_i)$
2. Phase two:
   Solve a TSP for each cluster by exact or heuristic method

This method can be solved by using Microsoft Excel [21].

III. RESULTS

A. *An Improved Clarkee and Wright Savings Algorithm – ICW*

In this following table III, there are basic input data that needs to be processed further:

TABLE III
BASIC INPUT DATA

CUST_ID	Latitude (S)	Longitude (E)	X	Y	DEMAND
DCH	**-6.187692**	**106.773820**	0.26	6.72	0
CG6	**-6.126652**	**106.713418**	7.05	0.00	0.78
CPM	**-6.174611**	**106.790322**	1.71	8.56	1.05
PRM	**-6.188177**	**106.734230**	0.20	2.32	1.71
KTA	**-6.155008**	**106.817747**	3.90	11.61	1.63
LMP	**-6.190000**	**106.738468**	0.00	2.79	0.46
GMP	**-6.160906**	**106.818575**	3.24	11.71	1.06
MTA	**-6.178593**	**106.792792**	1.27	8.84	1.12
NSF	**-6.174581**	**106.789918**	1.72	8.52	0.28
DCH = Distribution Center Head					
X and Y are in Kilometre (KM); Demand is in Meter cubic (M^3)					

TABLE IV
DISTANCE MATRIX

c_{ij}	City	V_0	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
		DCH	**CG6**	**CPM**	**PRM**	**KTA**	**LMP**	**GMP**	**MTA**	**NSF**
V_0	**DCH**	0	10	3	5	7	4	6	3	3
V_1	**CG6**	10	0	11	8	12	8	13	11	11
V_2	**CPM**	3	11	0	7	4	6	4	1	1
V_3	**PRM**	5	8	7	0	10	1	10	7	7
V_4	**KTA**	7	12	4	10	0	10	1	4	4
V_5	**LMP**	4	8	6	1	10	0	10	7	6
V_6	**GMP**	6	13	4	10	1	10	0	4	4
V_7	**MTA**	3	11	1	7	4	7	4	0	1
V_8	**NSF**	3	11	1	7	4	6	4	1	0

Where V is a vertice and V_0 is a depot

Table V
DEMAND VECTOR

V_i	d_i
V_1	0.78
V_2	1.05
V_3	1.71
V_4	1.63
V_5	0.46
V_6	1.06
V_7	1.12
V_8	0.28

The demand for each vector in table V is average demand per day for each outlet. The unit of measurement is in meter cubic and used for calculating the amount of truck needed.
After collecting these data, now savings matrix is created, for example for S_{12}:
$S_{12} = C_{01} – C_{02} – C_{12}$
$S_{12} = 10 + 3 – 11 = 2$

Table VI
SAVINGS MATRIX

s_{ij}	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
V_1	0	2	7	5	6	8	2	2
V_2		0	1	6	1	5	5	5
V_3			0	2	8	1	1	1
V_4				0	1	12	6	6
V_5					0	0	0	1
V_6						0	5	5
V_7							0	5
V_8								0

Table VII
SAVINGS LIST IN DESCENDING ORDER

s_{ij}	Savings	s_{ij}	Savings	s_{ij}	Savings
4-6	12	2-7	5	2-5	1
1-6	8	2-8	5	3-6	1
3-5	8	6-7	5	3-7	1
1-3	7	6-8	5	3-8	1
1-5	6	7-8	5	4-5	1
2-4	6	1-2	2	5-8	1
4-7	6	1-7	2	5-6	0
4-8	6	1-8	2	5-7	0
1-4	5	3-4	2		
2-6	5	2-3	1		

Now, two phase selection procedure is processed:

T = 5

Gene	1	2	3	4	5
S_{ij}	S_{46}	S_{16}	S_{35}	S_{13}	S_{15}
Savings (S_n)	12	8	8	7	6
P_n	0.29	0.20	0.20	0.17	0.15
q_n	0.29	0.49	0.68	0.85	1.00

r = 0.22

New Gene	1
S_{ij}	S_{46}
Savings (S_n)	12

T = 3

Gene	1	2	3
S_{ij}	S_{16}	S_{35}	S_{13}
Savings (S_n)	8	8	7
P_n	0.35	0.35	0.30
q_n	0.35	0.70	1.00

r = 0.19

New Gene	1	2
S_{ij}	S_{46}	S_{16}
Savings (S_n)	12	8

Fig 2. The Example calculation using Two Phase Selection Procedure

The process is repeated until all savings in table VII are selected as new gene. The result is in table VIII:

Table VIII
RESULTS OF TWO PHASE SELECTION PROCEDURE

s_{ij}	Savings	s_{ij}	Savings	s_{ij}	Savings
4-6	12	2-8	5	3-6	1
1-6	8	2-6	5	3-4	2
3-5	8	6-8	5	3-7	1
4-7	6	7-8	5	5-8	1
1-3	7	6-7	5	4-5	1
4-8	6	1-7	2	3-8	1
2-4	6	1-2	2	5-6	0
1-5	6	1-8	2	5-7	0
1-4	5	2-5	1		
2-7	5	2-3	1		

Table IX
ROUTE, DEMAND, DISTANCE - ICW

Truck no.	Route	Demand (M^3)	Distance (KM)
1	0-4-6-1-3-8-0; DCH - KTA - GMP - CG6 - PRM - NSF - DCH	5.46	39
2	0-2-7-5-0; DCH - CPM - MTA - LMP - DCH	2.63	15
	Total	**8.09**	**54**

B. *Karagul Tokat Aydemir – KTA Algorithm*

There are eight customer (C_1 to C_8). The demand of DCH is zero. The distance matrix and customer demands are in the following table X.

TABLE X
DISTANCE MATRIX AND CUSTOMER DEMANDS

		1	2	3	4	5	6	7	8	9
Demand (qi)			0.78	1.05	1.71	1.63	0.46	1.06	1.12	0.28
Customer		DCH	C1 - CG6	C2 - CPM	C3 - PRM	C4 - KTA	C5 - LMP	C6 - GMP	C7 - MTA	C8 - NSF
1	DCH	0	10	3	5	7	4	6	3	3
2	C1 - CG6		0	11	8	12	8	13	11	11
3	C2 - CPM			0	7	4	6	4	1	1
4	C3 - PRM				0	10	1	10	7	7
5	C4 - KTA					0	10	1	4	4
6	C5 - LMP						0	10	7	6
7	C6 - GMP							0	4	4
8	C7 - MTA								0	1
9	C8 - NSF									0

Then, solution weight matrix can be calculated and the results are in Table XI below:

TABLE XI
SOLUTION WEIGHT MATRIX

		1	2	3	4	5	6	7	8	9
Demand (qi)			0.78	1.05	1.71	1.63	0.46	1.06	1.12	0.28
Customer		DCH	C1 - CG6	C2 - CPM	C3 - PRM	C4 - KTA	C5 - LMP	C6 - GMP	C7 - MTA	C8 - NSF
1	DCH	-	0.96	0.39	1.06	1.41	0.23	0.79	0.42	0.10
2	C1 - CG6	0.96	0.96	0.54	0.82	0.66	0.97	0.59	0.53	0.74
3	C2 - CPM	0.39	0.54	0.39	0.61	1.36	0.55	1.13	5.56	3.00
4	C3 - PRM	1.06	0.82	0.61	1.06	0.60	4.79	0.54	0.60	0.67
5	C4 - KTA	1.41	0.66	1.36	0.60	1.41	0.63	6.60	1.34	1.60
6	C5 - LMP	0.23	0.97	0.55	4.79	0.63	0.23	0.54	0.47	0.60
7	C6 - GMP	0.79	0.59	1.13	0.54	6.60	0.54	0.79	1.11	1.34
8	C7 - MTA	0.42	0.53	5.56	0.60	1.34	0.47	1.11	0.42	3.00
9	C8 - NSF	0.10	0.74	3.00	0.67	1.60	0.60	1.34	3.00	0.10

Example calculation:

$$X_{23} = \frac{q_2.d_2 + q_3.d_3}{(q_2 + q_3).d_{23}}$$

$$X_{23} = \frac{0.78\,.\,10 + 1.05\,.\,3}{(0.78 + 1.05).\,11}$$

$$X_{23} = 0.54$$

Executing steps in Implementation phase when the maximum capacity of one vehicle or truck is 5.5 M^3, now the routes obtained are in table XII below:

TABLE XII
ROUTE, DEMAND, AND DISTANCE – KTA

Truck no.	Route	Demand (M^3)	Distance (KM)
1	0-9-6-8-4-7-2-0; DCH - NSF - LMP - MTA - PRM - GMP - CG6 - DCH	5.41	56
2	0-5-3-1-0; DCH - KTA - CPM - DCH	2.68	14
	Total	8.09	70

C. *Sweeping Algorithm – Cluster First Route Second*

Before determining cluster and route sequence, there are some datas that need to be obtained: theta, maximum capacity of one vehicle, and demands that in table XIII.

TABLE XIII
CAPACITY, COORDINATES, DEMANDS, THETA AND SEQUENCE

VEHICLE CAPACITY	5.5

DEPOT_ID	X	Y
0	0.26	6.72

Theta Ref
194

CUST_ID	X	Y	DEMAND	Theta	SEQ	CUST_ID
CG6	7.05	0.00	0.78	149.52	3	CG6
CPM	1.71	8.56	1.05	245.81	5	CPM
PRM	0.20	2.32	1.71	103.51	2	PRM
KTA	3.90	11.61	1.63	247.56	6	KTA
LMP	0.00	2.79	0.46	100.48	1	LMP
GMP	3.24	11.71	1.06	253.31	7	GMP
MTA	1.27	8.84	1.12	258.59	8	MTA
NSF	1.72	8.52	0.28	245.05	4	NSF

0 = Distribution Center

TABLE XIV
THE RESULT OF CLUSTERING

SEQ	CUST-ID	X	Y	DEMAND	VEHICLE-ID	SEQ	CML-LOAD	DISTANCE	KEY_VHSQ	CUST_ID
1	LMP	0.00	2.79	0.46	1	1	0	3.94	1-1	LMP
2	PRM	0.20	2.32	1.71	1	2	2.17	0.51	1-2	PRM
3	CG6	7.05	0.00	0.78	1	3	2.95	7.23	1-3	CG6
4	NSF	1.72	8.52	0.28	1	4	3.23	10.05	1-4	NSF
5	CPM	1.71	8.56	1.05	1	5	4.28	2.39	1-5	CPM
6	KTA	3.90	11.61	1.63	2	1	1.63	6.10	2-1	KTA
7	GMP	3.24	11.71	1.06	2	2	2.69	0.66	2-2	GMP
8	MTA	1.27	8.84	1.12	2	3	3.81	5.82	2-3	MTA

TABLE XVA.
THE RESULT OF REFINING ROUTE SEQUENCE– FIRST VEHICLE

VEHICLE-ID	SEQ	CUST_ID	X	Y	DISTANCE
1	0	0	0.26	6.72	0
1	1	LMP	0.00	2.79	3.94
1	2	PRM	0.20	2.32	0.51
1	3	CG6	7.05	0.00	7.23
1	4	NSF	1.72	8.52	10.05
1	5	CPM	1.71	8.56	0.05
1	6	0	0.26	6.72	2.34

TABLE XVB.
THE RESULT OF REFINING ROUTE SEQUENCE – SECOND VEHICLE

2	0	0	0.26	6.72	0.00
2	1	KTA	3.90	11.61	6.10
2	2	GMP	3.24	11.71	0.66
2	3	MTA	1.27	8.84	3.48
2	4	0	0.26	6.72	2.34

Then, from table XVa and XVb, the company needs two trucks to deliver demands and total distance is 36.71 KM which is in the following table XVI:

TABLE XVI

ROUTE, DEMAND, AND DISTANCE - SWEEPING

Truck no.	Route	Demand (M^3)	Distance (KM)
1	DCH - LMP - PRM - CG6 - NSF - CPM - DCH	4.28	24
2	DCH - KTA - GMP - MTA - DCH	3.81	12.58
	Total	**8.09**	**36.58**

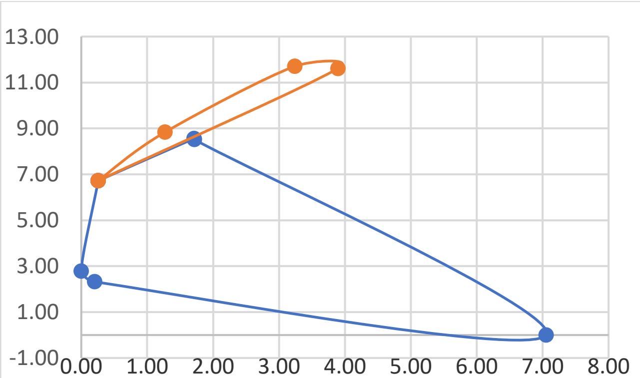

Fig 3. Graph of Clustering

Now, all of algorithms are compared in number of vehicles, routes, utilization and total distance in table XVII below:

Table XVII

COMPARISON OF ALGORITHM

Algorithm	Vehicle no.	Routes	Demand (M^3)	Capacity (M^3)	Utilization (%)	Distance (KM)	Total (KM)
ICW	1	DCH - KTA - GMP - CG6 - PRM - NSF - DCH	5.46	5.50	99.27%	39	54.00
	2	DCH - CPM - MTA - LMP - DCH	2.63	5.50	47.82%	15	
KTA	1	DCH - NSF - LMP - MTA - PRM - GMP - CG6 - DCH	5.41	5.50	98.36%	56	70.00
	2	DCH - KTA - CPM - DCH	2.69	5.50	48.91%	14	
Sweeping	1	DCH - LMP - PRM - CG6 - NSF - CPM - DCH	4.28	5.50	77.82%	24	36.80
	2	DCH - KTA - GMP - MTA - DCH	3.81	5.50	69.27%	12.8	

All algorithms show that to execute delivery for all outlets in West Jakarta need two vehicles that each has 5.5 m^3 capacity. ICW algorithm has the best utilization for the first vehicle and Sweeping algorithm for the second vehicle. Sweeping algorithm has the shortest total distance compared to two other algorithms. If the distance is shorter, theoreticaally the more economical fuel used which congestion factor neglected. The total distance produced by Sweeping algorithm is 48.57% shorter than KTA algorithm and is 33.33% shorter than ICW algorithm.

To strengthen this findings, various samples needs to be evaluated for larger sample size such as medium size around 30 sample sizes and 100 sample sizes.

IV. CONCLUSIONS

Sweeping algorithm has the shortest total distance compared to ICW and KTA algorithm for distributing goods from distribution center to all outlets in West Jakarta. All algorithm needs two vehicles. Larger sample size needs to be studied further to strengthen this findings.

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